NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1253

COMPARISON OF DESIGN SPECIFICATIONS WITH THE ACTUAL STATIC TRANSVERSE STABILITY OF 25 SEAPLANES

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SUMMARY

The maximum amount of transverse righting moment at rest actually provided by auxiliary floats or stub wings for 25 seaplanes is compared with the minimum righting moment required by certain design specifications. Large differences exist between the specifications and among the 25 designs studied. The adequacy of the actual transverse stability has been evaluated in terms of pilots' opinions. Based on these opinions, the U. S. Navy specification for transverse stability of seaplanes apparently will provide a wing-tip float having adequate displacement.

The cross wind required to submerge the tip float was computed for each seaplane. These results indicate that, for satisfactory transverse stability, seaplanes having a gross weight greater than 20,000 pounds require a critical cross wind in excess of 50 miles per hour and seaplanes of less than 20,000 pounds require a critical cross wind in excess of 25 miles per hour.

INTRODUCTION

Wing-tip floats or stub wings are customarily designed to provide sufficient static transverse stability when at rest in order to offset the static instability of the hull and wing group and to provide an arbitrary reserve of transverse righting moment. Differences in experience in the various types of seaplane operation (such as commercial, transport, and military) have resulted in the provision of greatly different amounts of reserve righting moment to compensate for the upsetting action of cross wind, waves, maneuvering at low speeds, and unbalanced loading.

Data are presented in this paper, in a form for easy comparison, to show the amount of transverse righting moment that has been

provided in each of 25 seaplanes of different designs (fig. 1) and to compare these righting moments with those required by design specifications. The adequacy of the actual transverse stability has been evaluated in terms of pilots' opinions. All the seaplanes except seaplanes 6, 22, 23, and 25 have been flown extensively. Seaplane 6 is of interest because it is designed for air-sea rescue operation, which includes operation in a very rough sea. Seaplanes 22, 23, and 25 are included because they are of notably large size.

Acknowledgement is made to the Bureau of Aeronautics, Navy Department, for the comments on the adequacy of the transverse stability of most of the examples of seaplanes used in this paper.

SYMBOLS

a length of water plane, feet

b beam, feet

b_w wing span, feet

B center of buoyancy of hull

B' center of buoyancy with tip float submerged

BG distance from center of gravity to center of buoyancy, feet

Bm distance from center of buoyancy to transverse metacenter without tip floats, feet

c distance from center of buoyancy of tip float to center line of hull, feet

d distance from center of pressure of the wing to the center line considering the wing as a flat plate of fractional aspect ratio, feet (fig. 6)

G center of gravity

GM metacentric height of seaplane with tip float or stub wing submerged, feet

GZ righting arm, feet (L/W)

h_e negative metacentric height of seaplane without tip floats or stub wings, feet

I moment of inertia of water-plane area about center line, $feet^4$

L net righting moment, pound-feet

m metacenter without tip floats or stub wings

M metacenter with tip float submerged

N wind force (approx. normal to the wing), pounds (fig. 6)

P engine power, horsepower

S wing area, square feet

v_h volume of displacement of hull, cubic feet (W/64 for sea water)

W gross weight, pounds

Δ buoyancy of hull or main float, pounds

Δ_t submerged displacement of tip float, pounds

ϕ_o angle of heel required for float to touch water, degrees

ϕ_1 angle of heel required to submerge float, degrees

θ_w angle of wave slope, degrees

METHOD OF ANALYSIS

Most of the data used in this analysis are included in table I and were obtained from manufacturers' drawings that showed the general arrangements of the seaplanes. Dimensions not given on the drawings were scaled off, and locations of the center of buoyancy not given on the drawings were estimated from the position of the load water line.

The negative metacentric height h_e of each seaplane without tip floats or stub wings was calculated by the equation

$$h_e = BG - Bm$$

where

$$Bm = \frac{3ab^3}{64v_h}$$

or

$$Bm = \frac{3ab^3}{W} \qquad (1)$$

which is considered in reference 1 to be sufficiently accurate if $Bm < \frac{1}{2}BG$. When $Bm > \frac{1}{2}BG$, the equation $Bm = \frac{I}{v_h}$ was used and the moment of inertia I of the area of the hull at the water line - commonly called the water plane - was approximated by

$$I = \frac{(a_1 + 4a_2 + a_3)b^3}{48} \qquad (2)$$

where the water plane is assumed to have the shape and dimensions shown in figure 2. For seaplane 15, the negative metacentric height was so small that equations (1) and (2) were not sufficiently accurate and the moment of inertia of the water plane was determined by graphical integration. For seaplane 10, although $Bm > \frac{1}{2}BG$, sufficient data were not available to determine the moment of inertia of the water plane accurately and the approximate value given by equation (1) was used.

The metacentric height GM of each seaplane with one tip float (or stub wing) submerged was calculated by

$$GM = \frac{L}{W \sin \phi_1}$$

The net righting moment L was found by subtracting the upsetting moment $Wh_e \sin \phi_1$ from the gross righting moment $c\Delta_t$. The net righting moments (fig. 3) of seaplanes 15 and 21 with stub wings were obtained from tests of a model in Langley tank no. 1. The maximum net righting moment of seaplane 15 occurs at an angle of heel of 12°; the maximum net righting moment of seaplane 21 occurs at an angle of heel of 13°.

The amount of reserve buoyancy provided by a tip float can be evaluated in terms of a righting moment. This righting moment may be considered as a product of the gross weight and a righting arm (GZ in fig. 4). In reference 2, this method was used for estimating the size of tip floats required for transverse stability of a seaplane.

This conception of a righting arm may be useful in comparing the relative stiffness and the natural frequency in roll. The magnitude of the righting arm as a fraction of the wing span is given by the ratio $\frac{L}{Wb_w}$ and is included in the tabulation of data for the 25 seaplanes (table II). The wing span is used in this ratio because the wing is indicative of the radius of gyration and the allowances that should be made for the upsetting motion due to cross wind and unbalanced loading of the wing.

The current U.S. Navy specification for transverse stability of seaplanes (reference 1) requires that the gross righting moment of a submerged wing-tip float must be equal to, or greater than, the value given by the equation

$$c\Delta_t = W\left(h_e \sin \phi_1 + \frac{0.10b_w}{W/S} + 0.06\sqrt[3]{W}\right) \tag{3}$$

Another specification for transverse stability of seaplanes is presented by Pritchard in reference 3, which requires that the buoyancy of wing-tip floats must be great enough to give a gross righting moment, when the float is completely submerged, of

$$c\Delta_t = W\left(h_e + \sqrt[3]{W}\right)\sin \phi_1 \tag{4}$$

The gross righting moments calculated from equations (3) and (4) are given in table II. Variation of maximum gross righting moment with normal gross weight of 24 of the seaplanes is shown in figure 5.

The cross wind that would completely submerge the tip float in a rough sea (called the critical cross wind) was calculated for each of the 25 seaplanes by using the formula presented by Wood in reference 4. According to this formula, the buoyancy of the tip float must be great enough to give a gross righting moment of

$$c\Delta_t = \frac{Wh_e \sin (\phi_1 + \theta_w) + Nd}{\cos (\phi_1 + \theta_w)} \tag{5}$$

when the float is completely submerged by the forces acting on the seaplane. These forces are shown in figure 6. Maximum values of the angle of wave slope θ_w are plotted against wind speed in figure 7 for shallow water and short fetch and for deep sea and long fetch. The values of θ_w were computed on the basis of trochoidal waves and were derived from unpublished data relating lengths and heights of waves in shallow waters and in deep sea to wind velocities.

Equation (5) was used to determine the velocity of the cross wind in a rough sea that would completely submerge the tip float having the actual displacement as given in table I. In order to compare the 25 seaplanes on the same basis, values of θ_w for deep sea were chosen for the calculations, although the smaller seaplanes normally would not be expected to operate in a deep sea.

RESULTS AND DISCUSSION

The values of the gross righting moments (table II), calculated from equations (3) and (4), are seen to differ greatly in the amount of righting moment required. Equation (4) generally gives a larger righting moment than equation (3). Both equations allow for the upsetting moment due to gravity $Wh_e \sin \phi_1$. All the reserve righting moment given by equation (4) is incorporated in one term, $W \sqrt[3]{W} \sin \phi_1$, whereas equation (3) allows for the effect of wind on the wings, $W\left(\frac{0.10b_w}{W/S}\right)$, and an excess righting moment, $W(0.06 \sqrt[3]{W})$, which seemed reasonable on the basis of accumulated Navy experience.

The gross righting moment as actually provided and as calculated from equation (3) using the seaplane dimensions given in table I

are shown as a function of the gross weight of the seaplane in figure 5. The righting moments calculated from equation (3) are approximated as a faired curve; the righting moments actually provided are plotted for comparison and the pilots' evaluations are indicated by the symbols. In general, the righting moment specified by reference 1 appears to be approximately the lower limit for satisfactory transverse stability of seaplanes based on the comments of several Navy pilot and civilian observers. (See table II.) The seaplanes that are considered to have marginal or unsatisfactory transverse stability (all but two light seaplanes) have less righting moment than required by the Navy specification.

The metacentric height GM of a ship is considered a measure of the transverse stability. In the case of a ship floating upright, or at small angles of heel, the tendency of the ship to return to the original position, when inclined away from that position, depends on the metacentric height. From these considerations, metacentric height would be expected to give an indication of the transverse stability of a seaplane. A study of the metacentric height GM of each seaplane as given in table II, however, indicates that no apparent relationship exists between the size, configuration, or gross righting moment and the metacentric height for the 25 seaplanes.

Values of the ratio $\frac{L}{Wb_W}$ are also given in table II. With the exception of one seaplane that had stub wings and one seaplane that was lightly loaded, the righting arms of all the flying boats are between 1.4 percent and 2.6 percent of the wing span. The righting arms of the single-float seaplanes 2, 3, 4, and 6 are between 3.2 percent and 4.5 percent of the wing span. These trends do not appear to be sufficiently consistent to serve as a design criterion.

The calculated cross wind required to submerge the wing-tip float for each of the 25 seaplanes, at rest or while taxiing at low speeds in a rough sea, is given in table II. The observed cross wind required to submerge the wing-tip floats for four of the seaplanes is also included in this table. In each case, this observed cross wind is less than the calculated value. A part of the discrepancy may be the result of the use of deep-sea conditions for the calculations of the cross wind. The conditions of the sea in which the observations were made are not known; the observations were probably made in shallow water. For a given speed, as shown in figure 7, θ_W for shallow water and short fetch is considerably greater than θ_W for deep sea and long fetch, with the result that the calculated critical cross wind would be lower if values

of θ_w for shallow water had been used. Propeller torque and a possible loss in buoyancy under dynamic conditions could also contribute to the discrepancy.

Seaplane 6 is an example of a new design for operation under very unfavorable conditions, such as in very rough sea. No report is available on its operation. The calculations, however, indicate that seaplane 6 has adequate tip-float displacement for operation when the cross wind is not in excess of approximately 68 miles per hour.

The gross righting moment of seaplane 21, which has stub wings, is markedly less than that specified by formulas (3) and (4). Several seaplanes of that design have been extensively used in world-wide commercial operations; some difficulty, however, has been experienced that would not occur in operating seaplanes with tip floats. One source of difficulty has been that, at an angle of heel of 0°, the stub wings are not so effective when the seaplane is lightly loaded as when it is heavily loaded. In addition, the calculated cross wing in a rough sea to exceed the gross righting moment for this seaplane is 15 miles per hour. Such a low value is believed to be undesirable even for commercial operations.

Seaplane 15, which is also of the stub-wing design, can operate safely in a much higher cross wind in a rough sea than seaplane 21. Seaplanes 15 and 21, however, are both considered unsatisfactory for military operation as determined by the experience of Navy pilots.

The calculated values of critical cross wind are shown as a function of the gross weight of the seaplanes in figure 8. The pilots' evaluations of transverse stability are indicated by the symbols. Military seaplanes of 20,000-pound gross weight or more appear to have been designed for operation in cross winds in excess of 50 miles per hour. Seaplanes of less than 20,000-pound gross weight appear to be satisfactory, although the critical cross wind may be as low as 25 miles per hour.

From a consideration of all the factors causing upsetting moments, it appears that the combination of the upsetting moments due to gravity, wind, and waves will result in the most unfavorable condition likely to be encountered in the operation of seaplanes. The effect of waves appears to be an important consideration in the design of wing-tip floats. Waves are, of course, a direct result of wind. The wave alone, however, contributes a large part of the upsetting moment. In a wave, the gravity component

$Wh_e \sin \phi_1$ becomes $Wh_e \frac{\sin (\phi_1 + \theta_w)}{\cos (\phi_1 + \theta_w)}$, and θ_w is frequently as large as ϕ_1. As the angle of heel of the seaplane becomes greater because of the wave slope, the normal component of the wind force on the wing is materially increased, thereby causing an increase in the upsetting moment.

CONCLUSIONS

The results of the present study of the transverse righting moments provided in each of 25 seaplanes are summarized as follows:

1. Large differences between the design specifications for transverse stability were shown to exist.

2. The U.S. Navy specification appears to be approximately the lower limit for satisfactory transverse stability of seaplanes based on the comments of observers.

3. For satisfactory transverse stability, seaplanes having a gross weight greater than 20,000 pounds have a computed critical cross wind in excess of 50 miles per hour. Seaplanes having a gross weight less than 20,000 pounds have a critical cross wind in excess of 25 miles per hour.

4. The upsetting moments produced by the action of waves appear to be an important consideration in the design of wing-tip floats.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., February 10, 1947

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TABLE I.- CHARACTERISTICS OF 25 SEAPLANES

Seaplane	Gross weight, W (lb)	Wing span, b_w (ft)	Wing area, S (sq ft)	Wing loading, W/S (lb/sq ft)	Beam, b (ft)	Engine power, P (hp)	Power loading, W/P (lb/hp)	Water-plane length, a (ft)	Distance from float to hull, c (ft)	BG (ft)	h_e (ft)	Angle of heel required for float to touch water, ϕ_o (deg)	Angle of heel required to submerge float, ϕ_1 (deg)	Actual tip-float displacement, Δ_t (lb)
1	4,500	40.0	245	18.4	4.25	400	11.2	24.0	14.35	3.7	2.5	0.8	8.0	405
2	4,800	36.0	262	18.3	3.67	----	----	24.7	14.3	5.8	5.0	1.0	8.7	750
3	5,403	38.0	290	18.6	3.68	----	----	25.3	15.0	5.5	4.8	.3	7.7	725
4	7,628	41.0	280	27.2	4.2	-----	----	27.2	18.5	6.3	5.5	.3	6.7	800
5	7,925	49.0	375	21.1	5.0	900	8.8	29.0	16.3	4.7	3.3	.6	9.1	760
6	10,164	50.0	413	24.6	6.0	1,200	8.5	38.0	22.0	4.5	2.1	0	7.0	1,150
7	14,910	72.8	1,171	12.7	8.3	1,520	9.8	34.2	24.0	6.7	2.2	1.2	6.8	1,380
8	15,985	100.0	1,115	14.3	8.5	-----	---	38.0	14.25	5.3	.9	Touch at rest	7.0	3,700
9	19,000	86.0	781	24.3	7.5	1,600	11.9	36.2	24.75	6.1	3.7	1.5	7.4	1,415
10	22,000	126.0	2,441	9.0	10.0	1,600	13.8	44.0	41.5	7.5	1.5	Touch at rest	4.5	1,800
[a]11a	29,421	104.0	1,400	21.0	10.2	2,400	12.3	39.7	44.6	7.6	1.9	.6	4.6	1,572
[a]11b	29,421	104.0	1,400	21.0	10.2	2,400	12.3	39.7	44.6	7.6	1.9	.6	4.6	1,775
12	41,145	118.0	1,406	29.3	8.5	3,200	12.9	55.2	35.3	7.0	4.5	1.1	7.5	3,059
[a]13a	46,000	110.0	1,048	43.9	11.5	4,600	10.0	50.0	37.75	9.5	4.5	0	7.5	2,600
[a]13b	46,000	110.0	1,048	43.9	11.5	4,600	10.0	50.0	37.75	9.5	4.5	0	7.5	3,826
14	46,500	118.0	1,408	33.0	10.0	3,400	13.7	58.1	40.9	8.2	4.4	1.7	5.6	3,670
[b]15	47,700	130.0	2,320	20.6	11.2	3,600	13.2	55.0	----	6.6	.5	---	---	-----
[a]16a	57,700	115.0	1,779	32.4	10.5	4,800	12.0	50.2	50.0	10.0	7.0	1.5	5.2	3,260
[a]16b	57,700	115.0	1,779	32.4	10.5	4,800	12.0	50.2	50.0	10.0	7.0	1.5	5.2	4,160
17	58,000	112.8	1,687	34.4	10.1	4,040	14.4	58.2	35.3	9.1	6.0	0	5.8	5,000
18	59,225	124.0	1,670	35.5	10.0	4,800	12.3	56.0	39.0	7.5	4.7	2.2	6.6	3,670
19	62,500	139.7	1,826	34.2	10.4	4,600	13.6	72.8	50.0	11.4	7.4	.9	7.3	5,504
20	75,000	112.8	1,687	44.5	10.8	6,200	12.1	65.8	35.3	9.0	5.7	0	5.8	5,000
[b]21	80,000	152.0	2,867	27.9	12.5	6,400	12.5	65.3	----	9.5	4.7	---	---	-----
22	121,500	169.0	2,600	46.7	13.3	8,000	15.2	77.0	46.6	10.1	5.6	0	6.0	10,500
23	130,000	150.3	2,636	49.3	12.5	9,320	13.9	80.2	50.3	10.0	6.4	.2	5.7	8,000
24	140,000	200.0	3,683	38.0	13.5	8,800	15.9	80.8	69.6	9.0	4.7	2.0	5.1	7,860
25	400,000	320.7	11,430	35.0	22.0	24,000	16.7	126.3	113.0	12.0	1.1	Touch at rest	3.5	22,656

[a]Two tip-float designs used for seaplanes 11, 13, and 16.
[b]Seaplanes 15 and 21 have stub wings.

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TABLE II.- CALCULATIONS FOR STATIC TRANSVERSE STABILITY AND COMMENTS OF OBSERVERS ON ADEQUACY OF ACTUAL TIP FLOATS

Seaplane	Gross righting moment (lb-ft)			Net righting moment, L (lb-ft)	GM with tip float submerged (ft)	$\frac{L}{Wb_w}$	Critical cross wind (mph)		Comments of observers (a)				
	Actual	From equation (3)	From equation (4)				Calculated	Observed	1	2	3	4	5
1	5,812	7,003	11,910	4,246	6.8	0.024	29.8	----	s		s		
2	10,720	9,465	15,930	7,060	9.7	.041	38.2	30.0	m				s
3	10,870	10,260	16,185	7,395	10.2	.036	37.5	----	m				
4	14,800	15,060	20,720	9,900	11.1	.032	44.8	----	s				s
5	12,388	15,450	29,130	8,250	6.6	.021	26.0	20.0	s	s	s	s	
6	25,300	17,820	29,390	22,720	18.3	.045	68.4	----					
7	33,120	34,320	46,320	28,350	16.1	.026	33.1	----			s		
8	52,725	37,050	50,830	50,975	26.2	.032	41.8	----		s	e		
9	35,020	46,180	74,350	25,960	10.6	.016	28.4	----		s		s	
10	74,700	70,340	50,960	72,110	41.8	.026	33.4	----					
[b]11a	70,110	73,590	77,830	65,630	27.8	.021	49.3	----	m		s		
[b]11b	79,160	73,590	77,830	74,680	31.6	.024	59.4	----	s				
12	107,980	125,980	209,580	83,810	15.6	.017	36.7	----	u	m	m		
[b]13a	98,150	137,790	241,750	70,870	11.8	.014	38.6	----	u				
[b]13b	144,400	137,790	241,750	117,120	19.5	.023	59.7	----	s				
14	150,100	136,890	183,030	130,140	28.7	.024	60.5	----	s	s	s	e	
[c]15	130,700	-------	-------	[d]128,000	12.9	.021	30.6	----		u			
[b]16a	163,000	191,200	241,000	126,040	23.9	.019	46.4	----	u	u			
[b]16b	208,000	191,200	241,000	171,040	32.4	.026	62.7	----	s	s	s		
17	176,500	188,850	262,800	141,350	24.1	.022	53.7	----	s				
18	143,130	191,100	297,180	111,350	16.4	.015	40.0	----					
19	275,200	233,000	374,000	216,440	27.3	.025	52.9	----	s	s	s		
20	176,500	252,040	438,070	133,300	17.7	.016	48.0	26.5	u				
[c]21	189,300	-------	-------	[d]122,000	24.8	.010	15.0	----	u	u			
22	489,300	476,250	700,160	418,180	32.9	.020	66.1	----					
23	402,400	517,080	736,900	319,800	24.8	.016	56.8	34.5					
24	547,060	568,280	704,700	488,570	39.3	.017	58.3	----	s	s		s	
25	2,560,130	2,163,950	1,830,600	2,533,230	103.7	.020	75.5	----					

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[a]Comments of observers are:
- s satisfactory
- u unsatisfactory
- m marginal
- e excellent

[b]Two tip-float designs used for seaplanes 11, 13, and 16.
[c]Seaplanes 15 and 21 have stub wings.
[d]Maximum value.

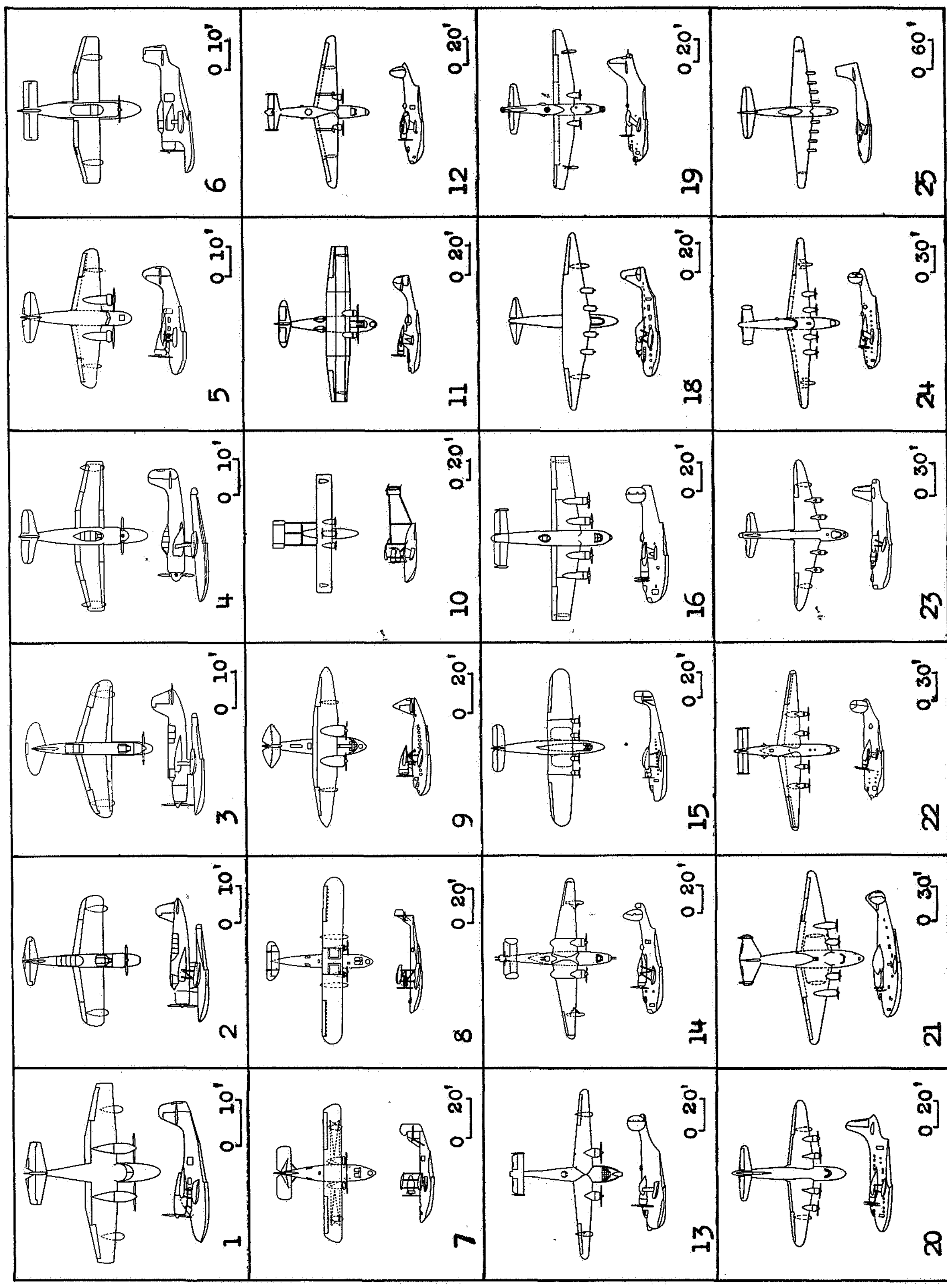

Figure 1.- Plan forms and side views of 24 seaplanes.

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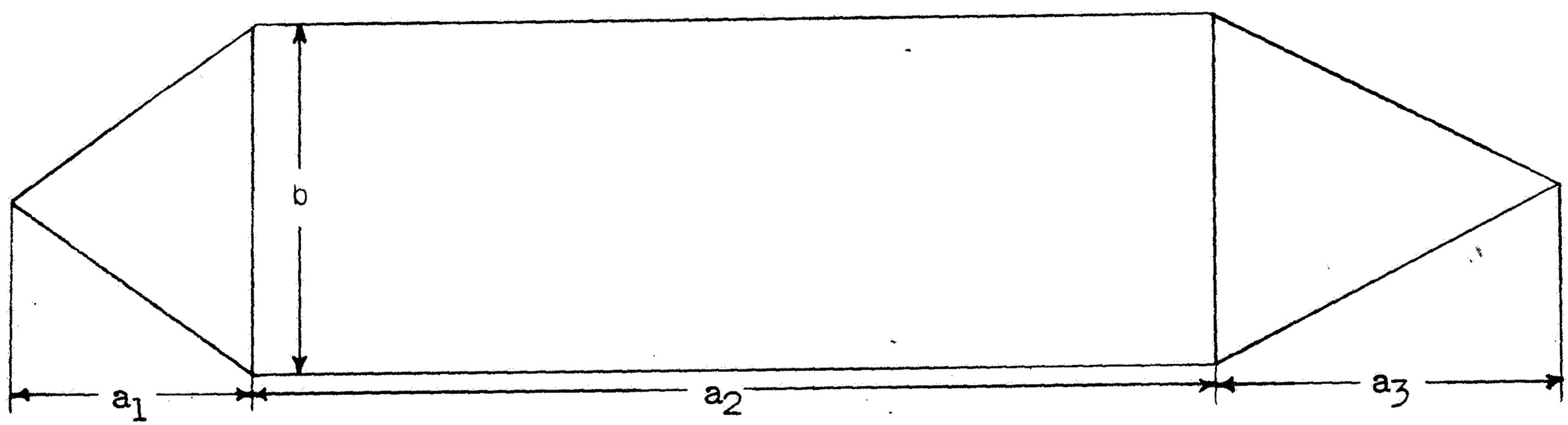

$$I = \frac{(a_1 + 4a_2 + a_3)b^3}{48}$$

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Figure 2.- Shape of water-plane area assumed in approximation of I.

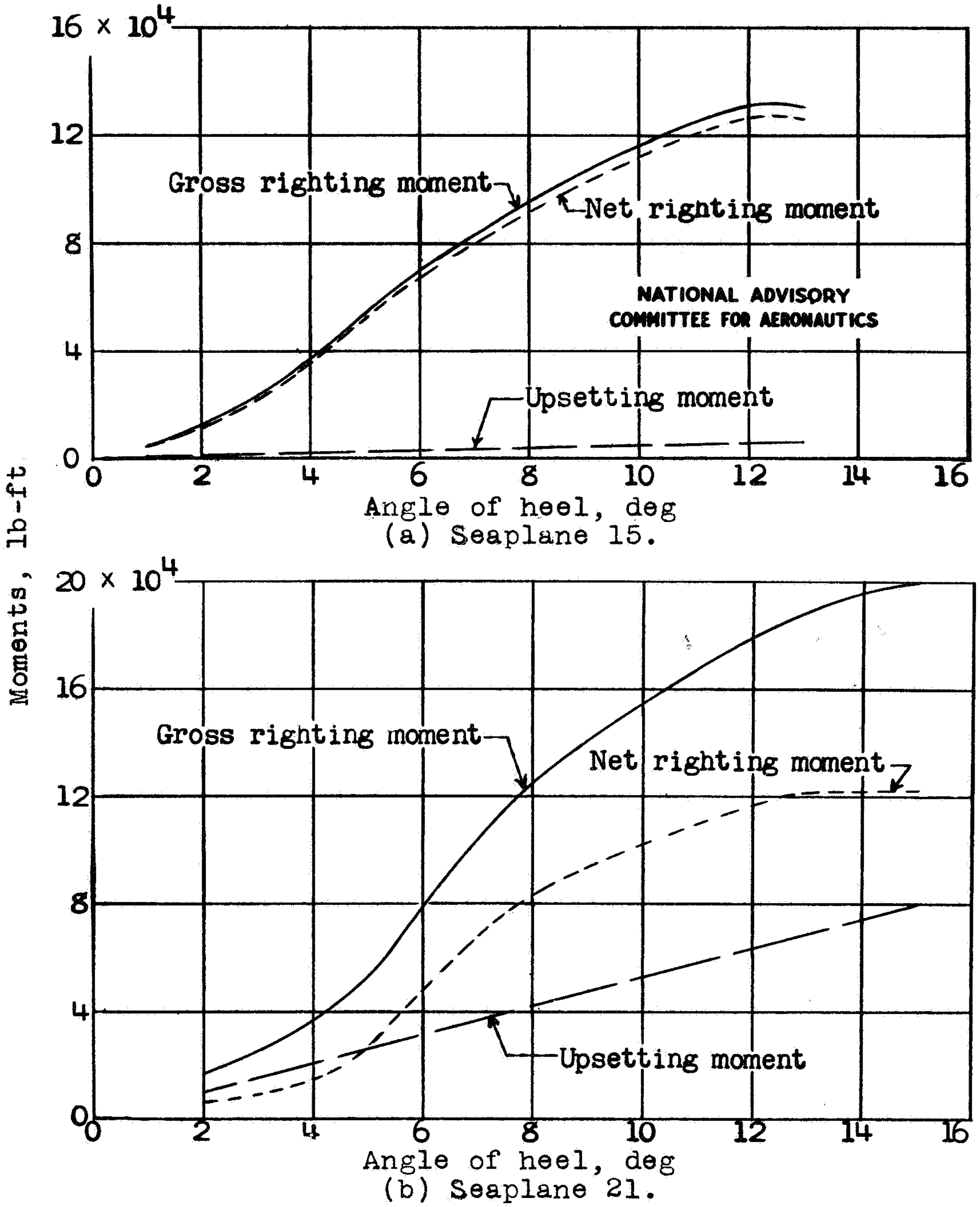

Figure 3.- Righting moments and upsetting moments of two seaplanes with stub wings.

G Center of gravity

B Center of buoyancy of hull

B' Center of buoyancy with tip float submerged

M Metacenter with tip float submerged

GM Metacentric height

GZ Righting arm, $\frac{L}{W}$

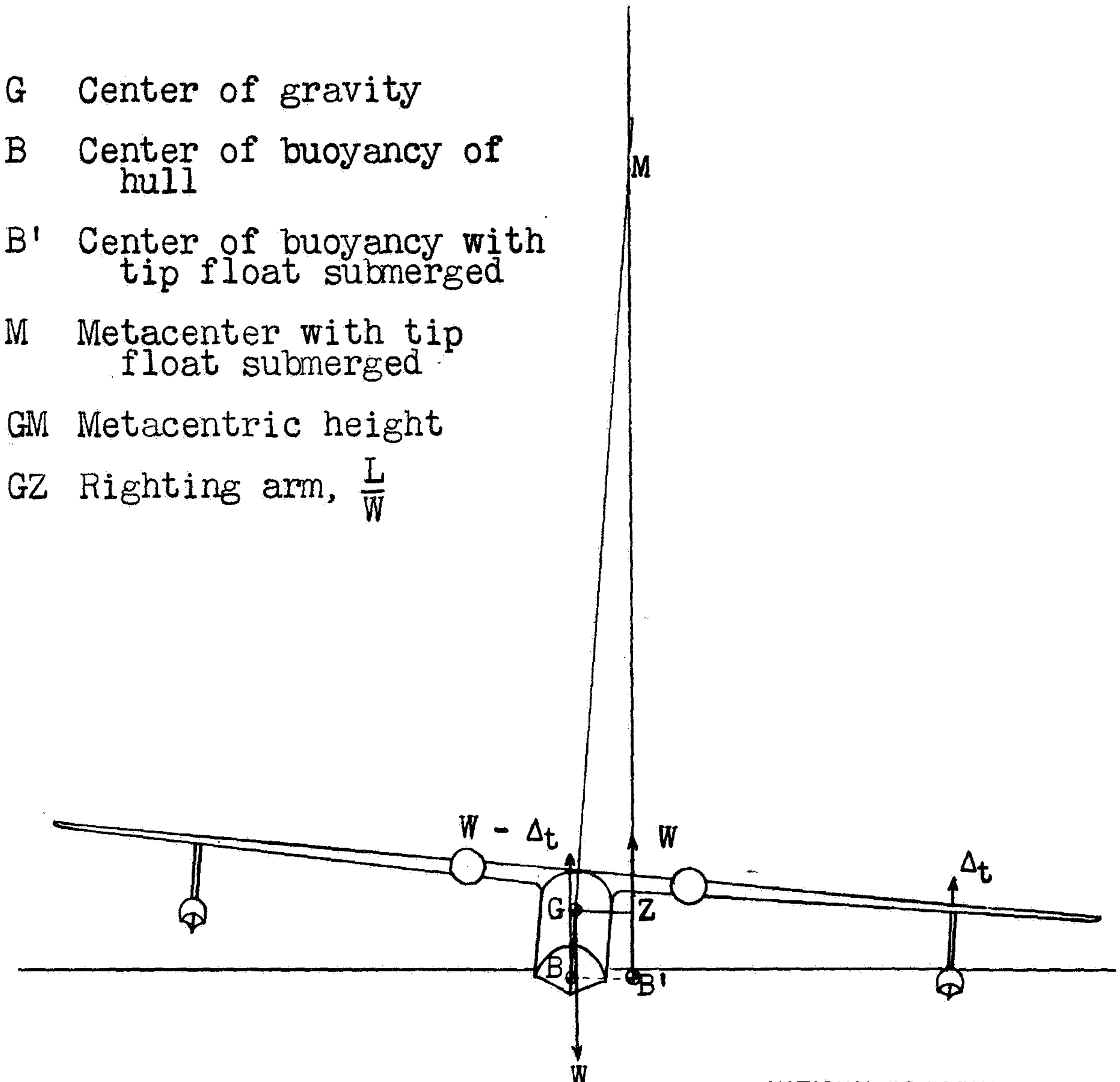

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Figure 4.- Location of center of gravity, center of buoyancy, metacentric height, and righting arm.

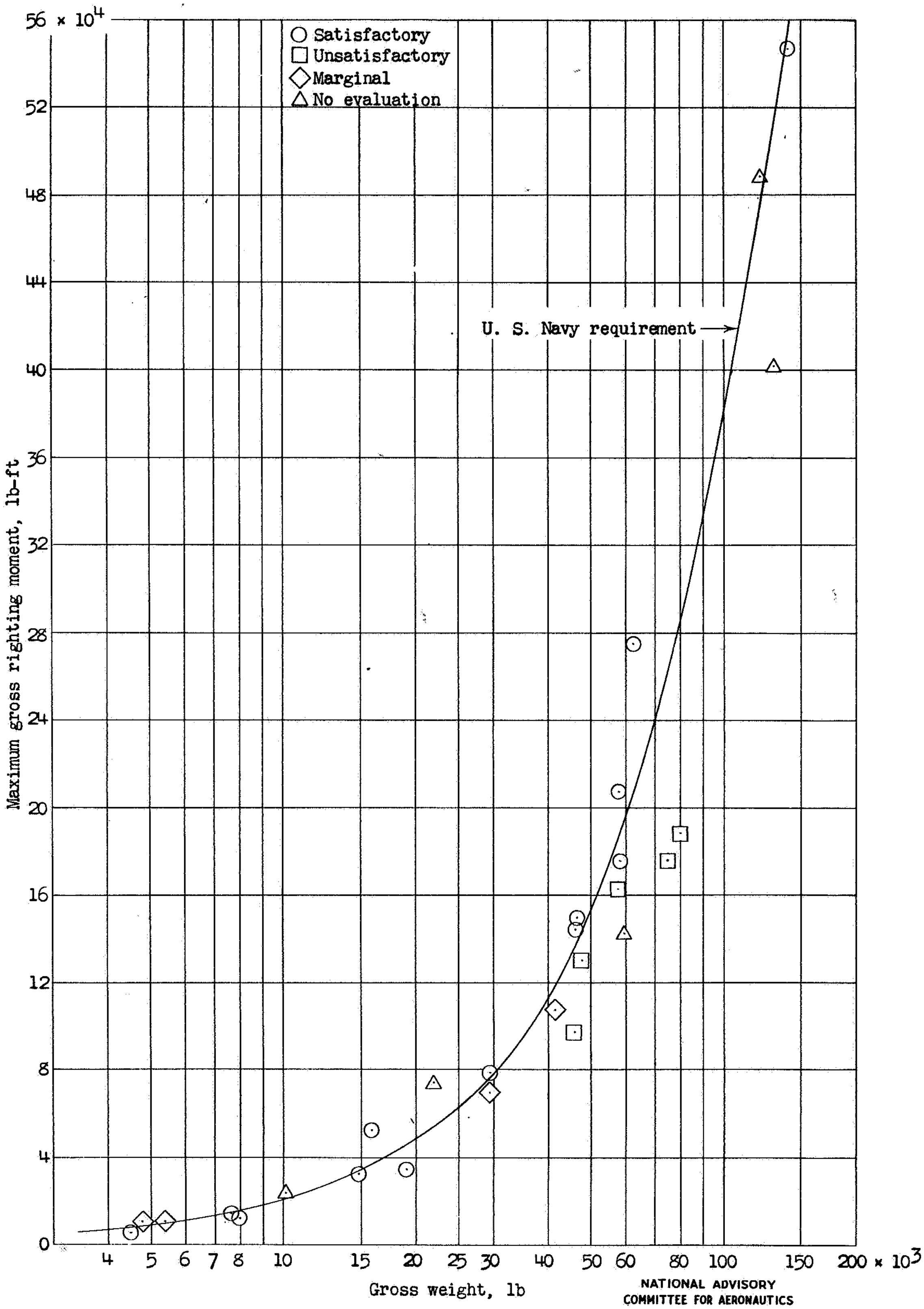

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Figure 5.- Variation of maximum gross righting moment with normal gross weight of 24 seaplanes.

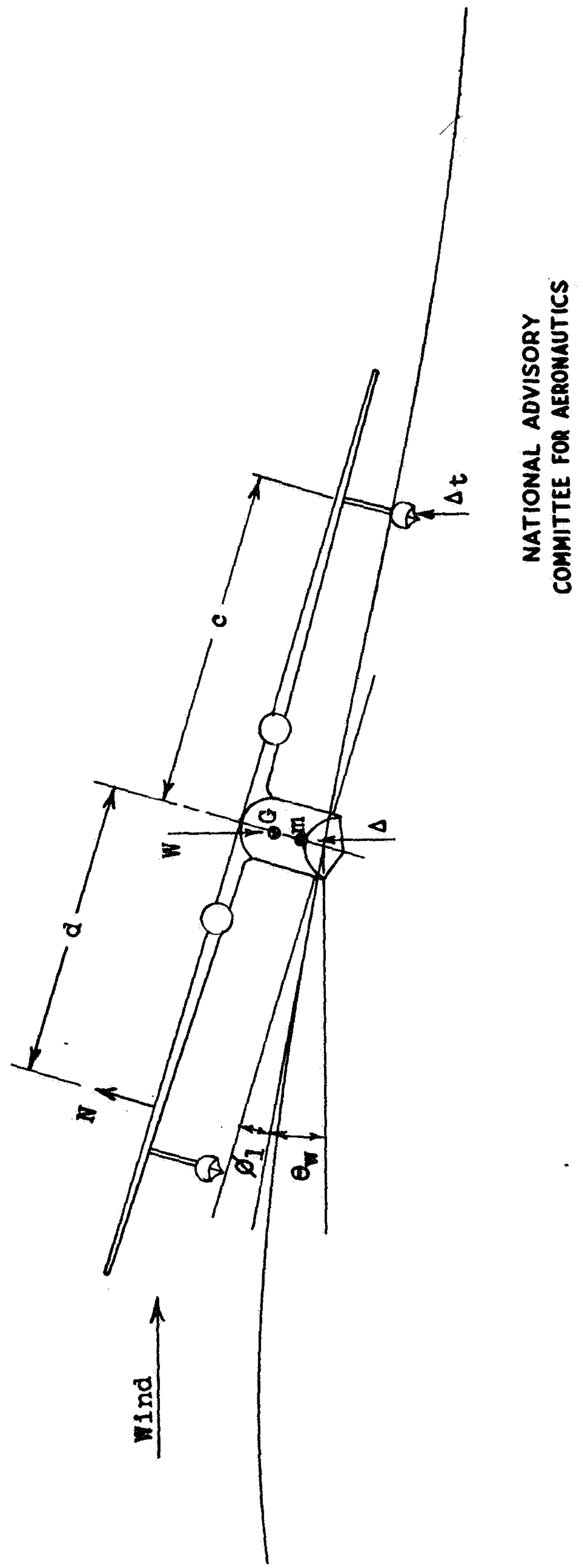

Figure 6.- Forces acting on a seaplane taxiing in cross wind in rough sea.

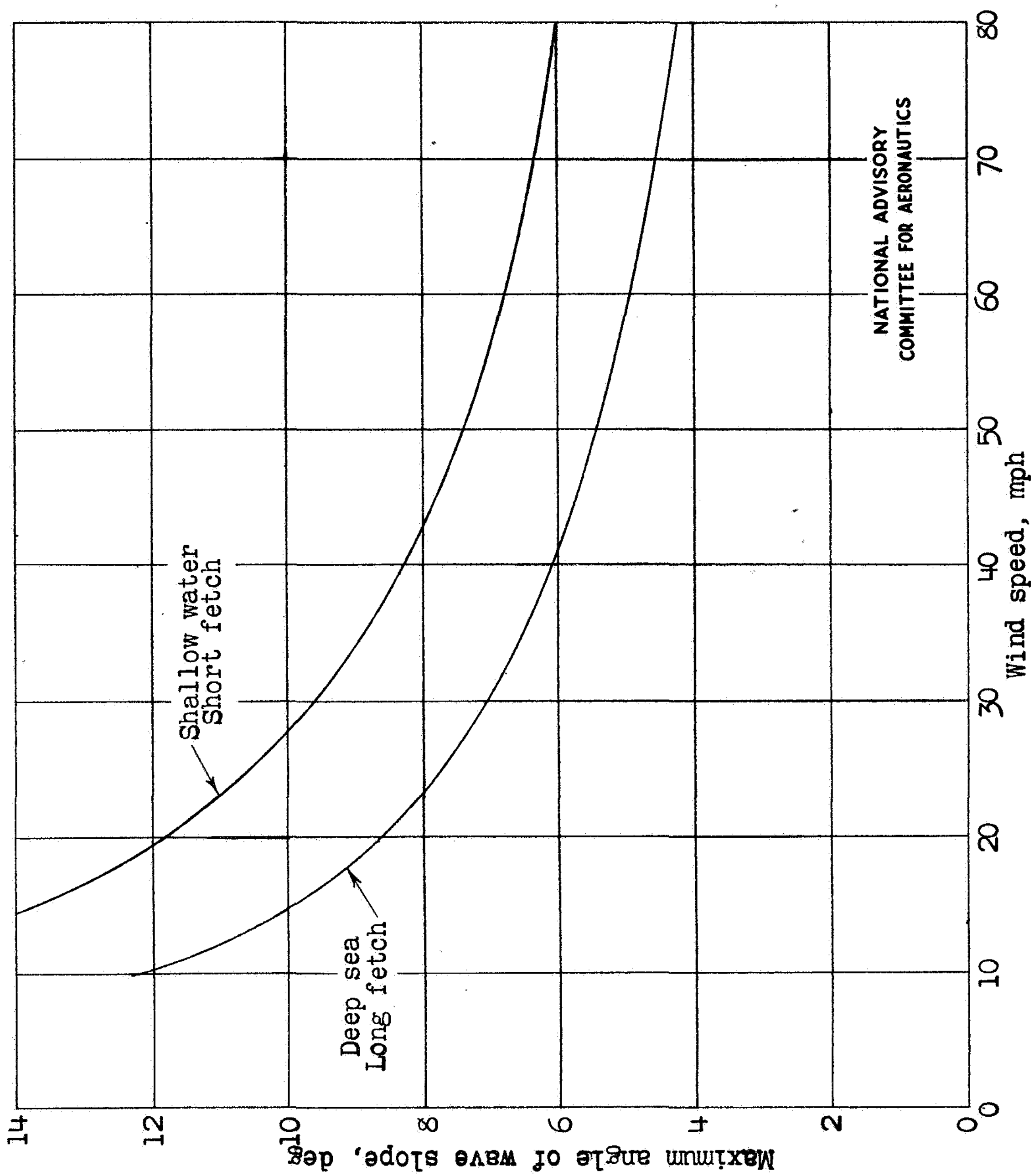

Figure 7.- Variation of maximum angle of wave slope with wind speed.

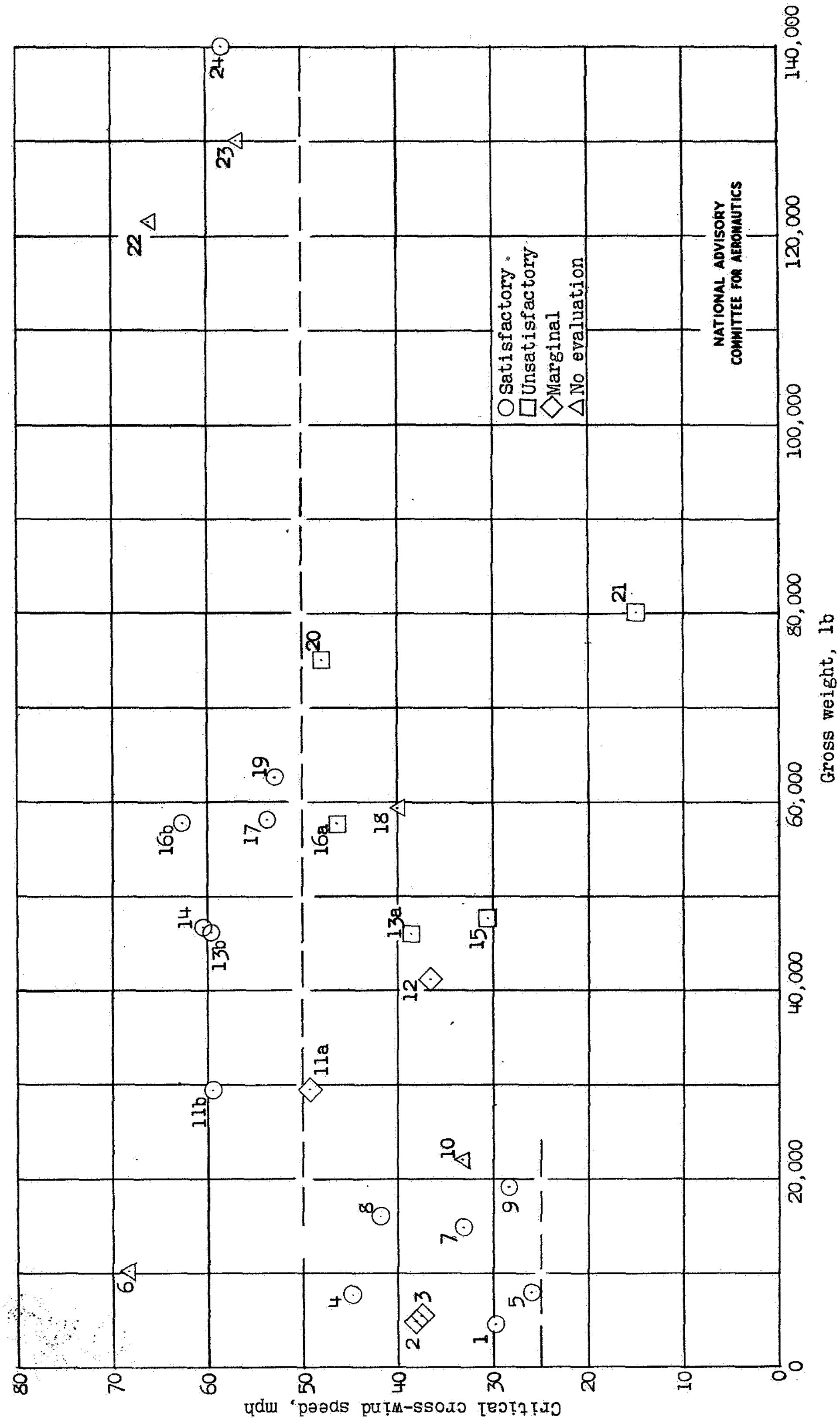

Figure 8.- Variation of critical cross-wind speed in a rough sea with normal gross weight of 24 seaplanes. Numbers refer to seaplanes.